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RESEARCH ARTICLE

EFFECT OF TERMITES INFESTATIONS ON MARKETABLE COCOA YIELDS IN DIFFERENT AGROFORESTRY SYSTEMS (SOUTH-WEST, CÔTE D'IVOIRE)

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ABSTRACT

Côte d'Ivoire, the world's largest producer of cocoa, is not outside the constraints linked to this crop. In addition to diseases like swollen shoot, certain bio-aggressors such as termites wreak havoc in cocoa trees. The objective of this study is to evaluate the yield loss linked to termite attacks on cocoa trees in different agroforestry systems. Yield was evaluated by selecting ten (10) infested and ten (10) non-infested cocoa trees in 30 m x 30 m quadrats installed in each plot. Agronomic parameters such as the number of pods per cocoa tree, the average mass of cocoa pod, the average mass of fresh cocoa beans in a pod and the average number of cocoa beans per pod were determined. Results show that the quantity of marketable cocoa varies between the different agroforestry systems. It is higher in full sun system (801.83 kg / ha) and lower in the shaded system (407.88 kg / ha). The estimation of the yield of healthy cocoa trees and infested cocoa trees makes it possible to clearly distinguish a difference between the yields. Termite infestations could have an effect on the yield of marketable cocoa. The search for methods to control these termites is therefore imperative.

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INTRODUCTION

The cocoa tree (*Theobroma cacao* L.) is cultivated for its beans and has a botanical origin in the rainforests of tropical America, where it occurs naturally (Braudeau, 1969). Cultivated for commercial purposes, *Theobroma cacao* belongs to the Malvaceae family. The *Theobroma* genus comprises twenty-two species, the only commercially cultivated species of which is used to prepare chocolate or extract cocoa butter (Mossu, 1990). In Côte d'Ivoire, cocoa is grown mainly in the forested southern half of the country (Assiri, 2010). With production of about 2 million tons for the 2023-2024 season (FIRCA, 2024), cocoa cultivation is a major source of income for thousands of small farmers in rural areas (Tano, 2012). Contributing more than 15% to the gross domestic product (Dufumier, 2016), cocoa cultivation plays a key role in the Ivorian economy and is therefore a strategic agricultural product for the country. However, many constraints threaten the sustainability of cocoa farming in Côte d'Ivoire (Assiri, 2007). Most of these constraints are attributed to the land use strategy, to which must be added crop losses due to disease, insects, birds, bats, squirrels, monkeys, rats and other pests. Increasingly perceived as an agent of deforestation (Bhagwat *et al*., 2008; Gnahoua *et al*., 2012), cocoa cultivation in Côte d'Ivoire has switched over the years from a shaded system to full sun system in order to increase its yield (Keli *et al*., 2005). This involved cutting down the forest and providing full light to the young cocoa trees, with food crops as temporary shade. This type of land use system helped to increase yields and propel the country to the number one position.

However, full sun system is very demanding in terms of phytosanitary protection measures and fertilizer inputs to maintain the system's sustainable profitability (COPAL, 2010). Several studies have pointed out that full sun systems generate invasion and recurrent epidemics of emerging pests such as termites (Ives *et al*., 2000, Hooper *et al*., 2005). Termites are social insects belonging to Isoptera order. They are widely distributed throughout the world, particularly in tropical, subtropical and semi-arid regions (Eggleton, 2000). In semi-arid zones, termites are the most active soil macrofauna (Lal, 1988). They account for almost 65% of the biomass of soil fauna (Goffinet, 1973). Despite the important ecological role they play in ecosystems, some termite species are considered pests because they cause damage. In fact, around 200 species of termites have been identified as pests of food crops, vegetables and industrial plants (Sand, 1973). Studies have shown that termites are one of the greatest pests of tropical agriculture and agroforestry (Mitchell 2002). Crop losses caused by termites are estimated at between 20% and 45% (Logan *et al*., 1990; Wood & Pearce, 1991). These insects dig galleries in the trunk and branches of cocoa trees, reducing the production potential of the attacked tree. In order to improve production, and as there are few studies on the impact of termite attacks on cocoa production, the present study was initiated to evaluate the effect of termite infestations on the marketable cocoa yield of different cocoa agroforestry systems.

MATERIALS AND METHODS

Study area: This study was carried out in the Nawa region (5° - 6° N and 7° - 8° W), specifically in the localities of Takoragui (05° 45' 18"

N - 06° 47' 30" W), Petit Bouaké (05° 56' 47" N - 06° 47' 30"W), Bobouho 1 (05° 35' 33" N - 06° 01' 53" W) and Gnaboya (06° 04' 31" N - 6° 54' 35" W) (Figure 1). Located in the south-west of Côte d'Ivoire, the Nawa region is headed by the town of Soubré, 370 km from Abidjan, the economic capital, and 130 km from San-Pédro, the country's second port. This region was chosen because it is one of the main cocoa-producing areas in Côte d'Ivoire. Nawa region supplies around 20% of national production (Conseil Café-Cacao, 2013). Nawa region is located in Guinean forest zone and has a typical equatorial climate with a bimodal rainfall pattern of two rainy seasons and two dry seasons. The rainy seasons are generally from April to June and September to October, while the dry seasons are from November to March and July to August. Average rainfall is between 1,300 and 1,600 mm/year, with 115 days of rain. Average temperatures are between 24°C and 27°C and can reach up to 30°C during the dry season. The vegetation of Nawa region, initially characterized by dense, humid forest or intermediate evergreen forest, has gradually been reduced in favor of huge plantations of perennial crops. The vegetation cover, similar to Taï National Park (536,000 ha), is now subject to abusive clearing by local population, as well as industrial purposes exploitation. Generally, almost all soils in the study area belong to ferralitic soil class. They are characterized by a great thickness (from 10 to 40 cm) and by a texture varying between a texture varying between clayey silt and silty sand (AGEROUTE, 2013). Deep and permeable, these soils are generally well suited to all types of food and industrial crops.

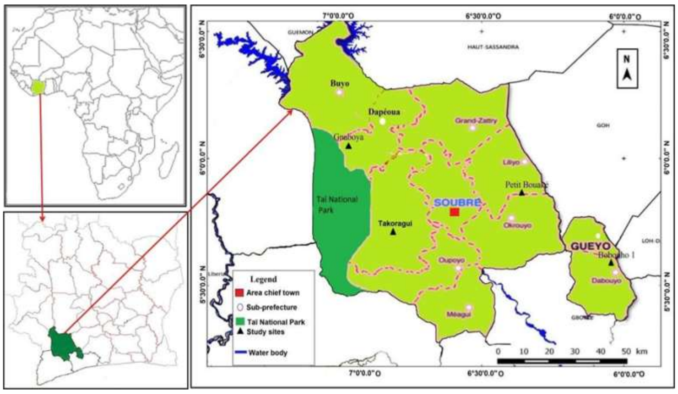

Figure 1. Location of the study area

Characteristics of the studyplots: The study was carried out on sixteen (16) cocoa farms in production in four localities. Four plots were chosen per locality, and each locality represents a cropping system. The plots were chosen on the basis of very specific characteristics. The plots ranged from full-sun systems to shaded systems and intermediate systems. The age of the plots varied from less than 5 years to 40 years. The cocoa farms were family-run and varied in size. The full sun system was selected in the Takoragui locality. In each plot of this system, four quadrats (30 m x 30 m) were installed. In this system, the number of shade trees within the quadrat was less than five, giving an equivalent of less than 56 trees per hectare. The locality of Petit Bouaké is represented by intermediate system 1, which lies between the two extremes, i.e. between full sun system and shaded system. This system was characterized by shade trees which between five and six per quadrat, equivalent to 56 to 67 trees per hectare. Bobouho 1 represents intermediate system 2. Like the first intermediate system, the second intermediate system is also between full sun system and shaded system. The difference is in the shade, which is closer to shaded system in the second intermediate system, whereas the first intermediate system is closer to full sun system. In this second intermediate system, the number of shade trees was between seven and nine per quadrat, i.e. between 78 and 100 trees per hectare. The Plots of shaded system were selected in the locality of Gnaboya (V4). In this system, the number of shadetrees in the quadrat was greater than or equal to 10 trees, i.e. a number of shade trees greater than or equal to 112 trees per hectare.

Data collection: Three varieties of cocoa are grown mainly on the plots in the study area. These are the 'French variety' (Amelonado), 'Ghana variety' (Forasteros) and 'Mercedes variety' (Hybrid). The 'Ghana' variety is still the most widely grown in the plantations. Given its dominance, 'Ghana variety' was chosen in each plot to measure agronomicparameters. In each cocoa farm, four quadrats (30 m x 30 m) were installed. Sixty-four quadrats were collected in the four localities, with sixteen quadrats per locality. Yield was assessed by selecting ten infested and ten non-infested cocoa trees in each quadrat. On either side of the cocoa trees selected, three pods were taken from each cocoa tree and agronomic parameters such as the mass of the cocoa pods and the number of pods per cocoa tree were measured. The cocoa pods were then shelled and the mass of fresh cocoa beans and the number of cocoa beans per pod determined. To determine the yield, the cocoa beans from infected cocoa trees were separated from the cocoa beans from healthy cocoa trees and weighed separately. The potential marketable cocoa yield (Rdtcm) was estimated according toequation:

Rdtcm (kg) = (Nbcab x Pdf x Ct) x d

Where,
Nbcab: average number of cocoa pods per cocoa tree,
Pdf: average weight of fresh cocoa beans per pod (kg),
Ct: transformation coefficient weight of fresh cocoa beans/weight of marketable cocoa
d: number of cocoa trees per ha.
The fresh bean weight / market cocoa weight transformation coefficient (Ct) is a variable considered to be constant (Braudeau, 1969; Lachenaud, 1984). The value of 0.35 was chosen (Lachenaud, 1984).

Statistical analysis: To assess possible variations between infested and non-infested cocoa trees, and cocoa trees under shade and without shade, comparison of means tests were used. Analysis of variance (ANOVA) tests were applied to agronomic parameters. The Tukey and Newman-Keuls multiple comparison tests were used to identify differences. For data not showing normality or homogeneity, the Kruskal-Wallis test was used; the significance level p = 0.05 was retained. Statistica 7.1 software was used.

RESULTS

Average number of cocoa pods per cocoa plant per plot according to shadesystem: Depending on the health of the cocoa tree and the type of cocoa, the number of pods differs from one agroforestry system to another (Table 1). In the full sun system, the average number of pods per cocoa tree in the four plots varied from 13.91±1.54 to 9.87±1.58 for healthy cocoa trees and from 13.66±2.25 to 9.16±1.21 for infested cocoa trees, with no significant difference. No significant difference was observed in the average number of cocoa pods per cocoa tree in the first intermediate system. In the second intermediate system, a significant difference was observed in the average number of cocoa pods per cocoa tree for healthy cocoa trees. The average number of pods varied from 14.16±1.65 for plot 4 to 8.58±0.69 for plot 1, with significance at p = 0.011. In the shaded system, no significant difference was observed in the average number of cocoa pods per cocoa tree among healthy cocoa trees. There was a significant difference between the average numbers of cocoa pods per cocoa tree in infested cocoa trees. This average number varied from 10.87±2.03 (plot 1) to 5.29±0.69 (plot 3) (p = 0.009).

Average weight of cocoapod: The average mass of healthy cocoa pod varied significantly (ANOVA, p = 0.001) from 506.69 g to 664.19 g in the plots of the full sun system (Table 2). It also varied significantly (p = 0.003) between plots of infested cocoa trees in the full sun system. There was no statistical difference in the average mass of the pods on the plots in the intermediate systems, except for the healthy cocoa trees in intermediate system 2, where there was a significant difference (p = 0.05) in the mass of the pods on the plots in this system. In the shaded system, the difference in the mass of the pod weight was observed in infested cocoa trees. In these plots, the average weight of the pods varies between 404.52 g for plot 3 and 514.5 g for plot 1.

Average number of cocoa beans percocoa pod: In the full sun system, the average number of beans per plot was statically identical in healthy cocoa trees (Table 3). However, the difference is significant in infested cocoa trees (p = 0.029) where the average number of beans varies from 33.81±1.65 to 39.92±1.19. In intermediate system 1, there was a significant difference (p = 0.003) in the different plots between the average number of cocoa beans per pod of infested cocoa trees. In the plots of intermediate system 2, it was in the healthy cocoa trees that there was a significant difference (p = 0.016) between the average number of cocoa beans. No significant difference was observed between the average numbers of cocoa beans in a pod in infested cocoa trees in the shaded system. A significant difference was observed in the average number of cocoa beans per pod in healthy cocoa trees (p < 0.0001) in this system. This average number of cocoa beans varied from 32.17±1.67 to 40.94±0.98.

Average weight of fresh cocoa beans percocoa pod: The average mass of fresh beans per pod varied significantly in all shading systems except for intermediate system 1 and infested cocoa trees in intermediate system 2, where no statistical difference was found (Table 4). In the full sun system, the average mass of fresh cocoa beans in a pod varied from 143.56 g (P2) to 194.97 g (P3) for healthy cocoa trees. In infested cocoa trees, the average mass of the cocoa beans varies between 140.22 g and 170.36 g. The average fresh beans mass of healthy cocoa trees in intermediate system 2 varied significantly (p = 0.0003) from 116.81 g for plot 3 to 162.36 g for plot 4. In the shaded system, the difference between the average mass of the cocoa beans was observed both in the healthy cocoa trees and intheinfested cocoa trees. The average mass of the cocoa beans varied from 119.39 g to 152.72g in healthy cocoa trees and from 123.22 g to 151.97 g in infested cocoa trees.

Estimation of production by crop system: The average number of cocoa pods per cocoa tree varies significantly from one system to another (Table 5). It is higher in the full sun system (12 pods / cocoa tree) and lower in the shaded system (8.81 pods / cocoa tree). This average number of cocoa pods also varied for infested cocoa trees (F = 14.63, p = 0.0037) (Table 6). It is 7.31 pods / cocoa tree for the shaded system and11.53 pods / cocoa tree for the full sun system. However, for healthy cocoa trees, the average number of cocoa pods per tree did not vary from one system to another. The average mass of cocoa pod varies significantly in the different agroforestry systems, regardless of the health status of the cocoa tree. The highest value for the average mass of cocoa pod (542.47 g) was observed in the full sun system. The mass of cocoa pod is statistically the same in the intermediate systems and in the shaded system. In the healthy cocoa trees, a significant variation in average pod mass was observed. It varied from 476.53 g for the shaded system to 565.76 g for the full sun system (F = 9.548, p < 0.0001). The same applies to infested cocoa trees, where the average mass of coccoa pod varies (F = 14.81, p < 0.0001) from 420.94 g for the intermediate system 1 to 527.90 g for the full sun system. The average number of cocoa beans per pod does not differ in the different agroforestry systems, whatever the state of health of the cocoa tree. The mass of fresh beans varies from one agroforestry system to another. It varies from 135.12 g in the intermediate system 1 to 160.41 in the full sun system. In healthy cocoa trees, the average mass of fresh cocoa beans varies from 137.66 g to 162.02 g respectively for the full sun system and shaded system, then from 124.45 g to 159.40 g for the full sun system and for intermediate system 1 in infested cocoatrees. The quantity of marketable cocoa produced per hectare was determined by considering the average density of cocoa trees (number of cocoa trees/hectare) in each agroforestry system. As the plots are farmers' plantations, most of them do not respect the density recommended by the organizations with recognized expertise in the field. Instead, each producer applies a density according to his own wishes. In the Takoragui locality (full sun system), the density of cocoa trees is the highest of all the agroforestry systems, with an average density of 1224.3 cocoa trees / ha. The intermediate systems have average densities of 1071.52 cocoa trees/ha and 924.3 cocoa trees / ha, for intermediate system 1 and intermediate system 2 respectively. The shaded system has an average density of 977.78 cocoatrees/ha. The average number of cocoa pods, the average fresh mass of cocoa beans and the average density of cocoa trees in the different agroforestry systems were used to estimate the marketable cocoa yield of the different Cocoa agroforestry systems. The quantity of marketable cocoa produced per hectare in the year varies between the different Cocoa agroforestry systems. It was highest in the full sun system (801.83 kg / ha) and lowest in the shaded system (407.88 kg / ha). However, if we consider the health status of the cocoa trees (healthy cocoa trees or attacked cocoa trees), the marketable cocoa yield also varies significantly from one agroforestry system to another. For healthy cocoa trees, the yield varied (F=5.84; p = 0.011) from 448.92 kg / ha / year for the intermediate system 2 to 860.57 kg / ha / year for the full sun system. Yield also varied (F = 11.2; p = 0.0008) in the infested cocoa trees from 339.62 kg / ha / year to 765.04 kg / ha / year for the shaded and full sun systems respectively. The full sun and intermediate system 1 recorded the highest yields of marketable cocoa, while the intermediate system 2 and the shaded system recorded the lowest yields. Yield estimates for healthy and infested cocoa trees show a clear difference betweenyieldsin the different cocoa agroforestry systems. In the full sun system, a yield difference of 95.53 kg / ha or 11.11% yield loss was observed. In the intermediate systems, the yield loss was 148.5 kg / ha (25.54%) and 96.01 kg / ha (21.38) for intermediate system 1 and intermediate system 2 respectively. The yield loss in the shaded system was 122.6 kg/ha or 26.52%. For all these plots, the potential marketable cocoa yield is positively linked to the average number of pods per cocoa tree. Potential marketable cocoa yield was not correlated with cocoa tree density.

DISCUSSION

The average number of cocoa pods per cocoa tree varies from one system to another. It is lower in the shaded system, but higher in the full sun system. The plant material used is more or less the same in the different agroforestry systems. This difference in the average number of cocoa pods could be due to shade. In fact, high shade could be a cause of the increase in brown rot in the shaded systems. In these systems, strong shade combined with environmental factors such as rainfall, high relative humidity and low temperatures create favorable conditions for the development of pod rot. This result corroborates those obtained by Kouadio *et al*. (2018) who found a low number of pods in complex cocoa agroforestry systems. For these authors, this low number of pods is linked to environmental conditions such as the density of associated trees, which would strongly influence the productivity of a cocoa tree. Shading modifies the quantity of light, temperatures and air movements in the cocoa grove and directly affects photosynthesis, growth and yield of the cocoa tree (De Almeida & Valle, 2007). Jagoret (2011) observed that the average number of pods per cocoa tree decreased significantly with the density of associated trees, the number of associated species and the density of foresttrees. The results show a significant variation in the average mass of a pod in the different agroforestry systems. The variation was observed regardless of the health status of the cocoa trees. The average mass of a pod is statistically the same in the intermediate systems and in the shaded system, but it is higher in the full sun system. The average mass of fresh beans variation follows the average mass of the cocoa pods. However, the type of Cocoa agroforestry systems hadn't influence the number of beans per pod. The average mass of a cocoa pod would therefore be a function of fresh beans mass or the mass of the shell of cocoa pod and would not depend on the number of beans. These two parameters can themselves be influenced by the type of Cocoa agroforestry systems, the type of soil and the type of plant material. These results align with those of Kouadio *et al.* (2018) who pointed out that the pods produced by cocoa varieties "Ghana cocoa" are larger than the "French cocoa" variety pods and produce beans of higher mass.

Table 1. Average number of cocoa pods per cocoa tree according to the health status of the cocoa tree

		Full sun system		Intermediate system 1		Intermediate system 2		Shaded system	
		CS	CI	CS	CI	CS	CI	CS	CI
Number of cocoa pods	P1	13.50 ±1.57 a	11.5±1.76 a	10.25±1.76 a	7.96±1.43 a	8.58±0.69 a	7.71±1.03 a	11.08±1.65 a	10.87±2.03 b
	P2	13.91 ±1.54 a	11.79±1.79 a	10.75±1.66 a	9.91±3.06 a	8.46±1.45 a	7.46±1.28 a	9.54±1.2 a	6.12±0.63 a
	P3	13.75±2.00 a	9.16±1.21 a	13.28±2.71 a	12.41±1.57 a	10.16±1.23 ab	8.46±1.26 a	6.54±0.75 a	5.29±0.69 a
	P4	9.87±1.58 a	13.66±2.25 a	9.75±1.0 a	7.91±1.06 a	14.16±1.65 b	11.58±1.68 a	13.25±2.62 a	6.96±0.75 ab
	p	0.283	0.376	0.559	0.321	0.011	0.124	0.055	0.009

P1: Plot 1; CS: Healthy cocoa trees; CI: Infested cocoa trees. Same letters in a same column show no significant differences (Tukey's post hoc test, at 5% threshold)

Table 2. Average weight of cocoa pods according to the health of the cocoa tree

		Full sun system		Intermediate system 1		Intermediate system 2		Shaded system	
		CS	CI	CS	CI	CS	CI	CS	CI
Mass of cocoa pods (g)	P1	534.28±23.63 a	457.08±21.01 b	496.28±26.08 a	413.39±19.21 a	477.78±28.54 a	431.14±23.36 a	501.28±26.73 a	514.5±31.72 b
	P2	506.69±34.44 a	512.11±22.04 ab	461.0±15.66 a	411.19±13.63 a	467.64±26.55 ab	416.27±18.51 a	482.89±21.89 a	454.72±24.11 ab
	P3	664.19±27.03 b	580.58±33.13 a	479.92±26.72 a	430.83±25.73 a	432.89±2.057 ab	440.75±18.20 a	463.06±26.29 a	404.52±19.29 a
	P4	557.89±31.52 ab	561.83±23.48 a	552.36±40.32 a	428.33±27.08 a	528.08±20.13 b	448.72±28.78 a	458.89±24.21 a	476.92±31.64 ab
	p	0.001	0.003	0.132	0.89	0.05	0.767	0.604	0.04

P1: Plot 1; CS: Healthy cocoa trees; CI: Infested cocoa trees. Same letters in a same column show no significant differences (Tukey's post hoc test, at 5% threshold)

Table 3. Average number of cocoa beans per pod according to the health of the cocoa tree

		Fullsun system		Intermediate system 1		Intermediate system 2		Shaded system	
		CS	CI	CS	CI	CS	CI	CS	CI
Number of cocoa beans per pod	P1	36.42±1.85 a	33.81±1.65 a	40.92±0.95 a	37.36±1.34 a	35.58±1.4 ab	38.25±1.22 a	40.94±0.98 b	35.11±1.97 a
	P2	38.31±2.01a	39.92±1.19 b	36.72±0.88 a	35.78±1.10 ab	38.72±1.08 ab	36.75±1.2 a	32.56±1.57 a	38.67±1.85 a
	P3	40.52±1.24 a	38.81±1.79 ab	39.17±1.29 a	38.11±1.68 a	34.81±1.19 a	36.53±1.15 a	39.0±1.48 b	39.22±1.68 a
	P4	36.69±1.76 a	38.67±1.49 ab	38.30±1.8 a	31.22±1.42 b	39.83±1.44 b	33.53±1.77 a	32.17±1.67 a	39.83±1.4 a
	p	0.32	0.029	0.141	0.003	0.016	0.101	< 0.0001	0.223

P1: Plot 1; CS: Healthy cocoa trees; CI: Infested cocoa trees. Same letters in a same column show no significant differences (Tukey's post hoc test, at 5% threshold)

Table 4. Average weight of fresh cocoa beans in cocoa pod according health of the cocoa tree

		Full sun system		Intermediate system 1		Intermediate system 2		Shaded system	
		CS	CI	CS	CI	CS	CI	CS	CI
Fresh mass of cocoa beans (g)	P1	156.67±6.69 a	140.22±7.02 b	150.44±6.11 a	125.917±5.33 a	135.14±9.27 ab	126.39±6.1 a	152.72±6.96 b	150.97±8.65 a
	P2	143.56±9.38 a	159.39±6.83 ab	131.47±5.57 a	128.05±4.21 a	137.78±7.58 b	129.08±5.04 a	119.39±6.43 a	132.83±7.53 ab
	P3	194.97±7.71 b	170.36±10.21 a	143.03±7.46 a	125.83±8.01 a	116.81±5.05 a	132.14±5.12 a	139.44±7.54 ab	123.22±5.97 b
	P4	152.88±9.62 a	167.84±6.86 a	155.06±10.43 a	118.0±6.5 a	162.36±6.6 c	122.83±7.85 a	139.08±7.15 ab	151.97±7.85 b
	p	0.0002	0.033	0.146	0.674	0.0003	0.741	0.011	0.018

P1: Plot 1; CS: Healthy cocoa trees; CI: Infested cocoa trees. Same letters in a same column show no significant differences (Newman-Keuls test, at 5% threshold).

Table 5. Agronomic parameters of cocoa trees in the fouragroforestry systems

Agronomic parameters	Average number of cocoa pods / cocoa tree	Average weight of a cocoa pod (g)	Average number of cocoa beans per pod	Average weight of fresh cocoa beans (g)	Marketable cocoa yield (Kg / ha / year)
Full sun system	12 b	542.47 b	37.87 a	160.41 b	801.83 b
Intermediate system 1	10.58 ab	475.14 a	37.86 a	139.02 a	538.28 ab
Intermediate system 2	9.92 ab	464.79 a	36.97 a	135.12 a	422.16 a
Shaded system	8.81 a	470.39 a	37.07 a	138.59 a	407.88 a
p	0.034	0.001	0.86	0.001	0.021

Same letters in a same column show no significant differences (Newman-Keuls test, at 5% threshold)

Table 6. Agronomic parameters of cocoa trees according to their state of health

	Average number of pods / cocoa tree		Average weight of a pod (g)		Average number of cocoa beans / pod		Average weight fresh beans (g)		Density (cocoa / ha)	Marketable cocoa yields	
	CS	CI	CS	CI	CS	CI	CS	CI		CS	CI
Full sun system	12.76±0.85 a	11.53±0.9 b	565.76±15.4 b	527.90±13.18 b	37.99±0.87 a	37.80±0.79 a	162.02±4.49 b	159.40±4.01 c	1224.3	860.57 b	765.04 b
Intermediate system 1	11.01±0.94 a	9.55±0.98 ab	497.39±14.42 a	420.94±10.95 a	38.78±0.65 a	35.62±0.73 a	145.0±3.85 a	124.45±3.07 a	1071.52	581.49 ab	432.99 a
Intermediate system 2	10.35±0.71 a	8.8±0.69 ab	476.6±12.28 a	434.22±11.24 a	37.24±0.66 a	36.26±069 a	138.02±3.85 a	127.61±3.05 ab	924.3	448.92 a	352.91 a
Shaded system	10.1±0.9 a	7.31±0.65 a	476.53±12.38 a	462.67±13.86 a	36.17±0.79 a	38.21±0.88 a	137.66±3.62 a	139.75±3.88 b	977.78	462.22 a	339.62 a
F	1.97	14.63	9.548	14.81	2.21	2.528	8.28	20.12		5.84	11.23
p	0.119	0.0037	< 0.0001	< 0.0001	0.086	0.0565	< 0.0001	< 0.0001		0.011	0.0008

CS: Healthy cocoa trees; CI: Infested cocoa trees. Same letters in a same column show no significant differences (Newman-Keuls test, at 5% threshold)

In addition, Youbi et *al*. (2018) showed that cocoa trees grown under shade have lighter cocoa beans than those grown in full sun.The average masses of fresh beans obtained in the different cocoa agroforestry systems are higher than the average value of 115 g of fresh beans per cocoa pod obtained by Babin (2009) following measurements carried out in 2003 and 2004 in different Cocoa agroforestry systems at Cameroon. This difference in mass could be linked to the many biological and physiological factors affecting bean weight. These different factors, such as nutritional factors, are important to determine average weight of a bean (Lachenaud, 1991).The average marketable cocoa yield from the cocoa farms in the different cocoa agroforestry systems gives values of 407.88 kg / ha, 422.16 kg / ha, 538.28 kg / ha and 801.83 kg / ha per year respectively for systems ranging from the most shaded to full sun. The quantity of marketable cocoa produced per hectare in the year is much higher in the full sun system and is almost double the yield produced in the second intermediate system and the shaded system. This yield dominance of the full sun system can be explained by cocoa productivity decreases when cocoa is grown under high shade (Braudeau, 1969; Jagoret, 2011). Indeed, it has been established that excessive shade creates a more humid microclimate, favoring the proliferation of diseases such as brown rot, which reduces production (Mossu, 1990; Boulay, 1998). In addition, the higher cocoa density in the full sun system compared with the other systems could be determining factor in yield increase. The Yields in the differentcocoa agroforestry systems are higher than the national average (395 Kg / ha / year) obtained by Assiri *et al*. (2009) and the average value of 325.85 Kg / ha obtained by kpangui (2015) in central Côte d'Ivoire. These yields are also higher than the value of 390 Kg / ha / year obtained by Freud *et al.* (2000) and Aguilar *et al.* (2003). Nevertheless, the yields of the intermediate 2 and shaded systems are comparable to the national average but lower than that obtained by Valet & Kouamé (2013) in the periphery of the Taï National Park, which was 455 Kg / ha. The yields recorded in the intermediate 1 system and full sun system exceeds the average yield obtained in Taï by Valet and Kouamé. The average yield of 801.83 kg / ha obtained in the full sun system is higher but close to the average yields of 700 kg/ha observed in some farmers' plantations (Assiri *et al*., 2009). These high yields are thought to be linked to study area, which Shelters 28% of Côte d'Ivoire's cocoa plantation and has the highest yields in Côte d'Ivoire (Kouassi, 2014). In addition, most of the plots in full sun system are dominated by plantations between 20 and 50 years old. The presence of a heterogeneous stand due to regular redensification could be one of the reasons for this result (Jagoret, 2011). It could also be due to a stand that has become vigorous over time. According to Youbi *et al.* (2018), a stand has become vigorous (deep rooting, high cocoa tree height) is more competitive and able to use the leached elements from soil at depth, which can improve cocoa tree productivity.

However, the results obtained contradict those of Petithuguenin (1995) and Ruf (1999), who observed in the west and south-west of the country, cocoa plantations degraded early, after 10 to 15 years of operation, under the combined effect of cultivation in fullsun. Despite the yields above the national average obtained in the study area, they are much lower than the average marketable cocoa yield of 2940 kg/ha obtained in Cameroon by Ondoua *et al.* (2014) with a density of 1111 plants/ha. This large difference in yield is thought to be linked to structure of the cocoa plant stand, particularly the plant material used. It has been established that hybrid cocoa agroforests perform better on average in terms of potential marketable cocoa yield than agroforestry cocoa plantations based on local varieties. The results show a yield differential between healthy and infested cocoa trees. The yield loss is evaluated at more than 95 kg / ha / year in all Cocoa agroforestry systems, and even approaches 150 kg / ha / year in some Cocoa agroforestry systems, resulting in a loss of income for producers. These yield losses in the different agroforestry systems are the consequence of the reduced activity of cocoa trees infested by termites and other pests. The potential yield of a cocoa farm depends on the average number of pods per cocoa tree and the density of the cocoa trees (Jagoret, 2011).

The average number of cocoa pods per cocoa tree is an essential component in determining yield. However, a plant attacked by pests has reduced physiological activity. This will result in a reduction in the number of cocoa pods and, consequently, a drop in cocoa production.

CONCLUSION

This study highlighted the influence of termite infestations on marketable cocoa yields in different agroforestry systems. It shows that the average mass of a cocoa pod is a function of either the mass of the fresh beans or the mass of the shell of the cocoa pod, and does not depend on the number of beans. The results also show a yield differential between healthy and infested cocoa trees. The yield losses in the different agroforestry systems are result of the reduction in the activity of cocoa trees infested by termite. The maintaining of cocoa trees productivity, it would therefore be important to consider awareness campaigns and appropriate control methods against these new emerging pests.

REFERENCES

AGEROUTE, 2013. Travaux pour l'amélioration de l'état du réseau prioritaire de pistes, agricoles dans la région de la Nawa (Soubré et Guéyo). *Revised report* 1, 362p.

Assiri, A. A. 2007. Identification of farmers' practices in cocoa orchard management in Côte d'Ivoire. DEA dissertation, agro-pedology option, University of Cocody-Abidjan, 56 p.

Assiri, A.A. 2010. Étude de la régénération cacaoyère en côte d'ivoire: impact des techniques de réhabilitation et de replantation sur le développement et la productivité des vergers de cacacaoyers (*Theobroma cacao L.*) en relation avec l'état du sol. Thèse de Doctorat,Universitéde Cocody, Abidjan, 170 p.

Assiri, A. A., E. A. Kacou, F. A. Assi, K. S. Ekra, K. F. Dji, J. Y. Couloud 2009. Agronomic characteristics of cocoa (Theobroma cacao L.) orchards in Côte d'Ivoire.*Journal of Animal and Plant Sciences*, 2: 55-66.

Babin, R. 2009. Contribution to the improvement of cocoa mirid control. *Sahlbergellasingularis*Hagl (Hemiptera: Miridae). Influence of factors on the population dynamics of the pest. PhD thesis, Université Montpellier III- Paul Valéry, Montpellier, France, 202 p.

Bhagwat, S. A., K. J. Willis, J. H. B. Birks, R. J. Whittaker (2008), Agroforestry: a refuge for tropical biodiversity? Trends in *Ecology and Evolution*, 23: 261pp.

Boulay, M. 1998. Étude de la phénologie de différents hybrides de cacaoyer associés à six espèces d'arbres d'ombrage, Master of Science thesis. Université Laval, Canada, 74 p.

Braudeau, J. 1969. The cocoatree. Ed. G.P. Maisonneuve et Larose, pp. 304.

Conseil Café Cacao, 2013. 2012-2013 cocoa marketing year/ Soubré: leading cocoa producer in Côte d'Ivoire, Thursday, October 17, 2013. http://www.conseilcafecacao.ci/ index.php?option=com_k2&view=item&id=223

COPAL, 2010. Workshop on soil management in cocoa orchards and agroforestry applied to cocoa production in West and Central Africa. Organised by COPAL, from 16 to 18 March 2010 in Kumassi (Ghana).

D.E.O. Kouassi, 2014. Etude de la diversité agro-morphologique du matériel végétal utilisé par les planteurs de cacao [(*Theobroma cacao* (L.), Malvaceae)] de la région de la Nawa en Côte d'Ivoire. Mémoire de maîtrise en protection et biologie végétale, UFR des Sciences de la Nature, Université NanguiAbrogoua (Abidjan, Côte d'Ivoire),65p.

De Almeida A. and R.R. Valle, 2007. Ecophysiology of the cacao tree. *Brazalian Journal Plant Physiology*, 19 : 425-448.

Dufumier, M. 2016. L'adaptation de la cacaoculture ivoirienne au dérèglement climatique: L'agroécologie pourrait-elle être une solution? Plate-Forme pour le Commerce Equitable.16p.

Eggleton, P. 2000. Global patterns of termite diversity. In: Termites: Evolution, Sociality, Symbiosis, Ecology, In: sociality, symbiosis, Abe T., D.E. and Bignell M. Higashi (Eds), Kluwer Academic Press, Dordrecht, 25-51.

FIRCA, 2019. Vision 2015-2020: FIRCA, a sustainable and innovative funding engine for the development of sustainable and competitive agriculture. *Annual report* 2019, 86p.

Freud, E. H. P. Petithuguenin, and J. Richard 2000. Les champs de cacao: un défi de compétitivité Afrique Asie. Editions Karthala and CIRAD, Paris, 207 p.

Gnahoua, G. M. Ouallou, K. and Balle P. 2012. Fast-growing legumes as shade plants in replanting cocoa trees in the semi-deciduous forest zone of Côte d'Ivoire. INAFORESTA symposium, Cocoa based Agroforestry: Sustainability and Environment. Yaoundé,21-22pp.

Goffinet, G. 1973. Contribution à l'étude de l'écosystème forêt claire (Miombo). Note 11. Etude Comparative des effectifs de quelques groupes arthropodiens du sol intercalique de quatre biotopes Katangais (Zaïre). *Annuaire Universitaire Abidjan Série E,* **6**:251-256.

Hooper, D. U. F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. D. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Seta, A. J. Symstad, J. Vandermeer, and D. A. Wardle (2005). Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *ecological monographs,* 75(1): 3-35

Ives, A. R. J. L. Klug, and K. Gross (2000). Stability and species richness in complex communities. *Ecol. Lett*. 3: 399-411.

Jagoret, P. 2011. Analysis and evaluation of complex agroforestry systems over the long term. Application to cocoa-based cropping systems in Central Cameroon.PhD thesis, SupAgro, Montpellier, France, 236p.

Keli, J. Z. Assiri, A. A. N. Koffi, J. N'goran, and I. Kebe 2005. Evolution of cocoa varietal improvement and cocoa production systems in Côte d'Ivoire. *Science Nature*, vol 2 No. 2:209-218

Kouadio, V. P. G. Vroh, B. T. A. Kpangui, K. B. A. S. F. Kossonou, and C. Y. Adou Yao 2018. Impact of shading on cocoa phenotypic traits in forest-savanna transition zone in central Côte d'Ivoire. *Cah. Agric.* 27: 55001.

Kpangui, K.B. 2015. Dynamics, plant diversity and ecological values of cocoa tree-based agroforests in the Subprefecture of Kokumbo (Central Côte d'Ivoire).Thèse de Doctorat, UFR Biosciences, Université Félix Houphouët-Boigny (Abidjan, Côte d'Ivoire), 277p.

Lachenaud, P. 1991. Fruiting factors in the cocoa tree (*Theobroma cacao L.*): influence on the number of seeds per fruit. Doctoral thesis, Institut national agronomique Paris- Grignon (Paris, France), 186p.

Lachenaud, P. 1984. A method for evaluating fresh bean production applicable to fully randomized trials. *Café Cacao Thé*, 1 (2), 21-30.

Lal, R. 1988. Effects of Macrofauna on soil properties in tropical ecosystems. *Agriculture, Ecosystem and Environment,* **24**: 101-116.

Logan, J. M. W. Cowie, R. H. and T. G. Wood 1990. Termites (Isoptera) control in agriculture and forestry by non chemical methods: a review, *Bulletin of Entomological Research*, 80: 309-330.

Mitchell, J. D. 2002. Termites as pests of crops, forestry, rangeland and structures in southern Africa and their control. *Sociobiology*, 40(1): 47-69.

Mossu, G. 1990. The cocoatree. Collection Le technicien d'agriculture tropicale. Paris: Maisonneuve et Larose, 160 p.

Ondoua, J., S. Dibong, V. Taffouo, andJ. Ngotta, 2014. Parasitism of cocoa seed fields by Loranthaceae in the locality of Nkoemvone (southern Cameroon). *Elewa Journal*, 1 (1): 8-10.

P.Aguilar, D. Paulin, Y. Keho, G. N'Kamleu, A. Raillard, O. Deheuvels, P. Petithuguenin, and J. Gockowski 2003. The evolution of cocoa orchards in Côte d'Ivoire between 1995 and 2002. *Proceedings of the 14* e *international conference on cocoa research,* 18-23 October 2003, Accra, Ghana, pp 1167 - 1175.

Petithuguenin, P. 1995. Cacaoculture et évolution du milieu : une contribution à la réflexion sur la reproductibilité de ces systèmes de cultures. Proceedings of the seminaron "Fertilité du milieu et stratégies paysannes sous les tropiques humides", 13-17 November 1995, Montpellier, France, 340-349p.

Ruf, F. 1999. How and why Côte d'Ivoire produces over one million tonnes of cocoa sustainably. *Afrique Agriculture*, 268: 21-25.

Sands, W. A. 1973. Termites as tree and crop pests. *Pest articles news summaries*, 19: 167- 177.

Tano, A. M. 2012. Cocoa crisis and strategies of producers in the sub-prefecture of Méadji in south-west Côte d'Ivoire. PhD thesis, University of Toulouse, 262 p.

Varlet, F. and G. Kouamé, 2013. Study of cocoa production in the riparian zone of the Taï National Park. Programme de Développement Économique en Milieu Rural (PRODEMIR), GIZ, 184 p.

Wood T. G. and J. M. Pearce 1991. Termites in Africa: the environmental impact of control measures and damage to crops, trees, rangeland and rural buildings. *Sociobiology*, 19: 221-234.

Youbi, P. H. F. Kaho, R. Ngoufo, M. Mbolo, and D. Edoa 2018. Yield evaluation of two cocoa varieties in the Central Region of Cameroon.*Revue Scientifique et Technique Forêt et Environnement du Bassin du Congo*, 10: 59-66.

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